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Chapter 8

Electromagnetic Radiation from Cellphone Towers: A Potential Health Hazard for Birds, Bees, and Humans

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Additional information is available at the end of the chapter

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Abstract

Microwave sickness syndrome was first identified in the 1950s by Soviet researchers. Symptoms included headache, fatigue, ocular dysfunction, dizziness, and sleep disorders. The main clinical manifestations were dermographism, tumors, blood changes, reproductive and cardiovascular abnormalities, depression, irritability, and memory impairment. Later in the 1970s, American researchers reported similar findings. Electromagnetic radiation (EMR) from modern cellphone towers is largely comprised of high-frequency radio waves or microwaves. The adverse biological effects of EMR from cellphone towers have been observed in birds, bees, and humans. The associated decline in fruit-eating seed dispersers such as wild birds and in insect pollinators such as bees could have serious consequences for human food production. In addition to noting this possible indirect effect of microwave radiation, a direct effect on human health was evaluated. According to a new approach to cancer risk assessment, based on an apoptotic model of carcinogenesis, it was determined that proximity to EMR from cellphone towers may pose a potential cancer risk in humans since microwave radiation can induce various apoptotic pathways leading to cell death in transformed human cell lines. The stimulation of cellular apoptosis resulting in deregulated cell proliferation is being increasingly linked to cancer and may provide a possible mechanism for microwave radiation carcinogenesis.

Keywords: electromagnetic radiation, microwave radiation, radiofrequency radiation, microwave radiation carcinogenesis, apoptosis

1. Introduction

The electromagnetic spectrum consists of ionizing and nonionizing radiation. Ionizing radiation includes ultraviolet (UV) rays, X-rays, and gamma (ϒ) rays. Electromagnetic radiation

(EMR) from cellphone towers is largely comprised of high-frequency radio waves or microwaves. Microwaves lie in the nonionizing radiation portion of the electromagnetic spectrum which includes low-frequency (computers, power lines), medium-frequency (television, radio), and high-frequency (microwaves, mobile devices) radio waves (**Figure 1**).

Radio-frequency radiation (RFR) is emitted at varying frequencies by cellphone towers, cell phones, computers, Wi-Fi, microwave ovens, and other electronic devices. RFR frequency ranges between 10 KHz and 300 GHz. On average, Wi-Fi applications and microwave ovens utilize 2450 MHz. Cellphone technology uses transmission signals between 800 MHz and 3 GHz, while cellphone towers typically operate at 1900 MHz [1].

The adverse biological effects of EMR from cellphone towers have been reported in frugivores such as potential fruit-eating seed dispersers (birds), insect pollinators (bees), and humans. A decline in sparrow populations and other wild birds has been observed in the vicinity of cellphone towers in India. EMR from similar sources has also been correlated with decreased egg production in honey bees. In fact, in India, the problem is perceived as being sufficiently serious that a panel of scientists has recommended regular auditing of EMR levels and that EMR be recognized as a pollutant. They have also suggested implementation of a special law to protect urban flora and fauna from its effects [2–4].

The significant radioisotopes released as a result of the Chernobyl nuclear reactor explosion were iodine-131, cesium-137, strontium-90, and plutonium-241. Some of these radioisotopes

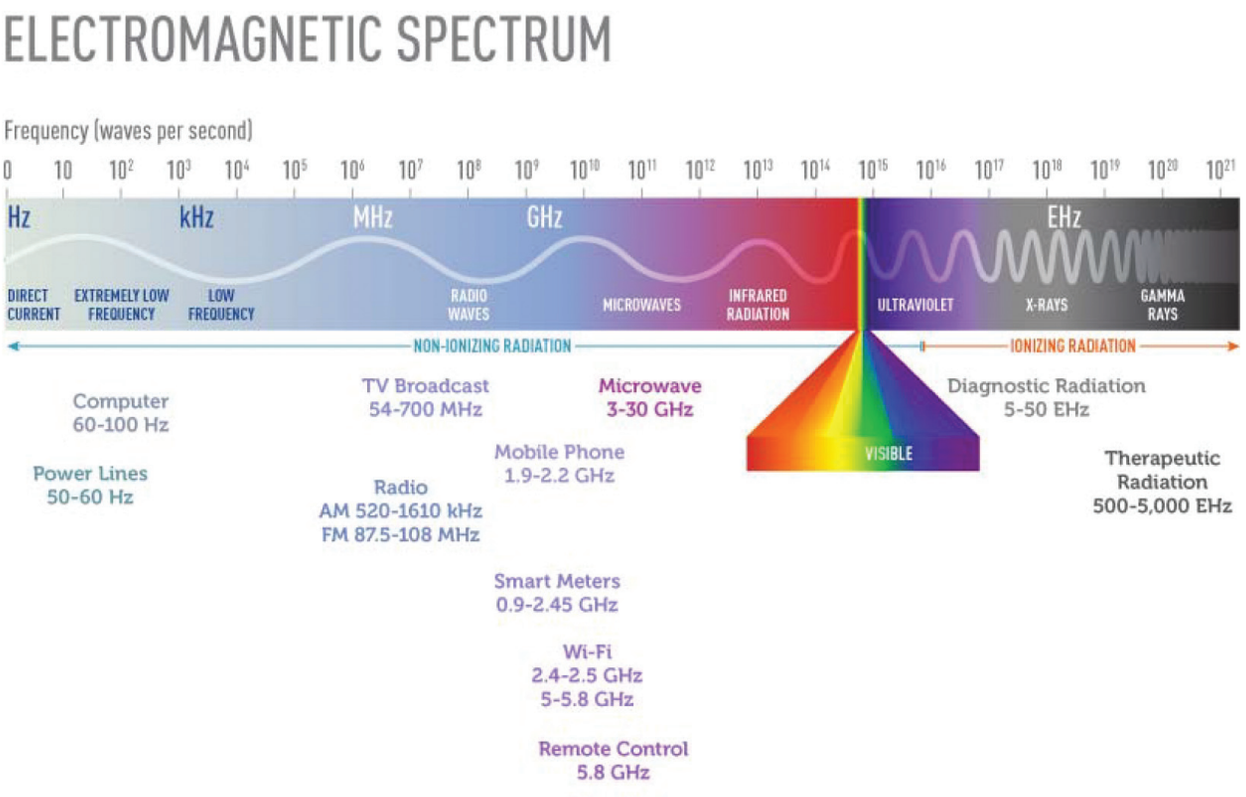

Figure 1. National Cancer Institute – National Institute of Health; 2016.

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such as cesium-137 are emitters of gamma radiation. Cesium is one of the radioactive fission products routinely produced by a nuclear reactor during its operation. However, following the Chernobyl event, forest food products in surrounding regions of Europe were found to contain the highest recorded levels of the radioisotope cesium-137. For example, high contamination of reindeer meat was reported in Scandinavia. Pollen data from forests in the Bavarian Alps also show that radiocesium uptake by mosses uniquely reference the Chernobyl incident [5].

Previously, a local reduction in pollinators like bumblebees in the vicinity of Chernobyl has been linked to the production of fewer fruit and stunted fruit trees in highly radioactive areas. Moreover, a direct link has been established between radiation, pollinators, fruit abundance, and an abundance of frugivores such as fruit-eating seed dispersers [6]. Therefore, due to the observed reduction in wild birds and honey bees, it is possible that EMR may negatively impact fruit production, which is an important food crop, in areas of high cell tower concentration. It has already been reported that EMR from cell towers can affect the overall growth of agricultural crops and plants by reducing yield [2]. Since growing certain fruits rich in micronutrients may be beneficial in helping to prevent cancer, such a decline in crop yield could represent a significant loss for the agricultural industry as the demand for these phytochemicals like the polyphenols found in grape skin and grape seeds grows (resveratrol and procyanidins) [7].

In addition to this indirect effect on human health, the potential for a direct effect of EMR on human health was investigated. The adverse health effects of EMR from cell base stations and other cellular infrastructure are certainly contentious. Epidemiological data are lacking in this area and, at times, it is contradictory. Exposure levels are often difficult to quantify due to background EMR including from cell phones, computers, Wi-Fi, microwave ovens, and other electronic household devices. However, there is some research that suggests a degree of caution should be exercised in the installation of such cell base stations. Moreover, substantial evidence relating to microwave radiation exposure exists.

Microwave sickness syndrome was first identified in the 1950s by Soviet medical researchers. Symptoms included headache, fatigue, ocular dysfunction, dizziness, and sleep disorders. Clinically, dermographism, tumors, blood changes, reproductive and cardiovascular abnormalities, depression, irritability, and memory impairment were reported. Although the syndrome is reversible in its early stages, it is considered to be lethal over time [8].

Later American researchers found symptoms to include eczema, psoriasis, and allergic and inflammatory reactions in staff stationed at the US Embassy in Moscow, which the Soviet government irradiated secretly over a period of approximately 20 years. It is of interest that the power densities of the microwaves employed by the Soviets were comparable to modern cellphone base stations. They also observed neurological problems in males, reproductive problems in females, tumor increases (benign in men, malignant in women), hematological alterations, effects on mood and well-being, and eye problems. The average exposure time for each individual was between 2 and 4 years [9].

Despite these observed effects and other existing data, no satisfactory explanation for tumor formation based on classical experimental carcinogenesis models has been available so far.

Such traditional models rely heavily on DNA damage and the subsequent clonal expansion of mutated cells for their modality. In the past, it has been stated that no mechanism is known to cause cancer in the nonionizing radiation or radiofrequency radiation part of the electromagnetic spectrum since it does not damage DNA or cells directly like ionizing radiation [10]. Thus, it has been largely dismissed as a putative cause of cancer. However, recently, it has become apparent that the pathogenesis of cancer is closely connected with aberrantly regulated apoptotic cell death and the resulting deregulation of cell proliferation. A mechanism for gamma-radiation carcinogenesis based on an apoptotic model has already been proposed [11]. According to a new approach to cancer risk assessment, it was determined that EMR from cellphone towers may pose a cancer risk in humans since microwaves can stimulate p53-mediated caspase-3 activation and cell death in a human brain glioblastoma cell line [12] and Fas-induced and ERK-mediated apoptosis in human lymphocyte cell lines [13, 14].

2. Epidemiology

Aside from the Moscow study of the US Embassy staff, early epidemiological data were gathered from technically trained US naval officers routinely exposed to radar by Robinette et al. [15]. Radar transmission generates electromagnetic waves in the microwave domain. Interestingly, both these groups showed an elevated incidence of leukemia. In another large Polish study, military personnel exposed to radiofrequency microwave radiation from radio and radar showed very significant elevations in leukemia and other cancers [16].

The first epidemiological studies on populations living near cell base stations focused mainly on cognitive changes and neurobehavioral effects and started being conducted in 2002 [17]. However, an early Egyptian cellphone tower study in the Algharbia governate area (1999–2002) suggested an increase in the overall cancer rate of the local population by 7.5% [18]. Later, a German study found elevated cancer incidence in patients who had lived 5–10 years within 400 meters of a cell installation [19]. Another Israeli study indicated an association between increased cancer incidence and living in proximity to a cell base station [20].

There also appears to be a significant body of evidence suggesting that cell phones, which use EMR in the microwave range, can cause brain tumors and disturb brain function [21, 22]. One Swedish study reported that cellphone radiation increases the human brain tumor rate by 2.5 times [23]. In fact, in his extensive review on the subject, Cherry concludes that over 40 studies have revealed adverse biological or human health effects specifically from cellphone radiation and that there is extremely strong evidence that cell sites are risk factors for brain tumors and leukemia [24].

It should be noted that children may be more susceptible to damage from cellphone radiation since their bodies are still developing. There is epidemiological evidence to suggest that children are susceptible to leukemia from high power voltage (HPV) lines which emit low-frequency radio waves [25, 26]. Although no epidemiological data seem to have been collected

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in children regarding exposure to high-frequency radio waves, there are reports that cellphone radiation penetrates deeper into the head of children and that certain tissues of the head like the bone marrow and eye absorb more radiation than in adults [27–29]. Specific absorption rate (SAR) is the term used to describe the absorption of RFR in the body and represents the rate of energy absorbed by a unit of tissue.

3. Animal studies

In vivo animal studies have demonstrated that potentially genotoxic effects in male Wistar rats following microwave exposure include the induction of micronuclei, an increase in the production of reactive oxygen species (ROS) which can trigger cellular apoptosis, and increases in various antioxidant enzyme activities like serum glutathione peroxidase, superoxide dismutase, and catalase [2]. Rats exposed to microwaves display a significant reduction in splenic activity of natural killer cells, which may help to provide host defense against the development of tumors [30]. Other cellphone radiation research in animals has shown that it doubles the cancer rate in mice [31]. Also, EMR from cellphones can increase mouse tumor necrosis factor (TNF) production, which is associated with a major apoptotic pathway [32]. Cellphone radiation increases the embryonic mortality of chickens [33].

In vitro, one very elegant set of comparative studies correlating results in human lymphocytes with Chinese hamster cells (V79) has suggested that microwave radiation can induce structural damage in mammalian chromosomal DNA. A significantly higher frequency of specific chromosome aberrations, such as dicentric and ring chromosomes, was observed in irradiated V79 cells than in control samples. Micronuclei were also present in the irradiated V79 cells [34]. Animal studies have demonstrated the neoplastic transformation of a clonal mouse embryo cell line (C3H/10 T1/2) following exposure to modulated microwaves [35]. In other more recent studies, neural cell apoptosis in NGF-differentiated PC12 rat cells has been induced by microwave exposure via the mitochondria-dependent caspase-3 pathway [36]. It represents one of three cellular apoptotic pathways including the extrinsic death receptor-dependent pathway, the intrinsic mitochondria-dependent pathway, and the intrinsic endoplasmic reticulum(ER) stress-mediated pathway [37].

4. Cell studies

Microwave irradiation can produce genotoxic effects in human cells [38]. Induction of micronuclei in human lymphocytes with wide interindividual variability after exposure in vitro to 1800 MHz [39] has been observed and is correlated with specific chromosomal aberrations (acentric fragments and dicentric chromosomes) [40]. Exposure of human peripheral blood lymphocytes to EMR associated with cell phones (830 MHz) leads to chromosomal instability, specifically aneuploidy, which is known to increase cancer risk [41]. Aneuploidy among other kinds of DNA

damage can result in p53-mediated postmitotic apoptosis in human cells [42]. EMR from cell base stations has also been reported to increase the frequency of DNA strand breaks in the lymphocytes of cellphone users and in individuals residing near cell base stations [43, 44].

Cellphone radiation can increase c-fos proto-oncogene activity by more than 40% in embryonic mouse cells and alter c-jun proto-oncogene activity in rat cells [45, 46]. However, there is some conflicting data on this subject, and reports can be inconsistent, while data in humans appear to be lacking. Additionally, there is no evidence to suggest that microwaves can cause point mutations, which are associated with oncogene activation in humans and other mammals [47]. Nevertheless, the c-fos protein can induce cellular apoptosis, and the c-jun gene product has been found to be necessary for neuronal apoptosis in human and other mammalian cells [48, 49]. Microwaves can affect chromatin conformation and histone phosphorylation in human lymphocytes, as well, which may be associated with epigenetic mechanisms at the cellular level [50]. A significant increase in the efflux of calcium ions has been observed in human neuroblastoma cells at extremely low levels of microwave radiation indicating a high degree of sensitivity [51]. This cellular calcium imbalance may reflect the release of calcium ions from internal organelles like mitochondria and the endoplasmic reticulum [ER] as occurs in response to certain heavy metals, and this process is linked to an apoptotic pathway [11].

Microwaves have been reported to induce ERK-mediated apoptosis and cell cycle arrest in a dose-dependent manner in a human natural killer cell line (NK-92) just 1 hour after exposure, which could lead to general immune suppression and the development of tumors [13]. Activation of the Ras/Raf/ERK pathway has been associated with both the intrinsic mitochondrial and the extrinsic death receptor apoptotic pathways [52]. Continuous microwave irradiation (2.45 GHz) can cause Fas-induced apoptosis via the extrinsic death receptor pathway in a human Jurkat T-cell line [14]. Fas is a member of the tumor necrosis factor receptor (TNFR)/nerve growth receptor (NGR) family. In another recent study, microwave radiation exposure from a GSM cellphone simulator (900 MHz) also resulted in a significant increase in the apoptotic rate of a human T-cell line (Jurkat cells) [53]. In addition, the formation of ROS in normal human peripheral blood mononuclear cells can stimulate apoptosis in response to 900 MHz cellphone radiation. In this case, apoptosis is induced via the mitochondrial pathway and is mediated by ROS [54]. Finally, apoptosis can be stimulated in human brain glioblastoma cells directly in response to microwaves. EMR exposure in the cell base station frequency range [1800 MHz] induces apoptosis-related events such as ROS bursts and oxidative DNA damage, which in turn promote p53-dependent caspase-3 activation through release of cytochrome c from mitochondria [12].

5. A possible mechanism of carcinogenesis

Cellphone radiation can alter c-fos and c-jun proto-oncogene activity, and both these gene products have been implicated in the activation of cell death signal transduction pathways [48, 49].

DNA damage including micronucleus formation, chromosomal aberrations, and DNA strand breaks has been reported in human cells in response to microwave radiation. Certain kinds of

DNA damage like aneuploidy can result in cell cycle arrest and activation of apoptosis. Double-strand breaks in DNA caused by radiation can also signal apoptosis.

The generation of reactive oxygen species in response to microwave radiation has been observed in various studies. Certain carcinogens like UV rays exert some of their carcinogenic effects via the generation of reactive oxygen species in the cell [55]. This is true of X-rays, as well [56]. Certain oncogenic proteins such as Ras also produce elevations in ROS upon stimulation. Many genes and proteins that respond to conditions of oxidative stress within the cell subsequently trigger apoptosis. Because mitochondria are important regulators of cellular redox status, the induction of oxidative stress exhibits its effects upon these organelles to trigger the intrinsic apoptotic pathway via cytochrome c release and caspase cascade activation [57, 58].

Moreover, an increase in the efflux of calcium ions has been observed in human neuroblastoma cells at extremely low levels of microwave radiation, and this cellular calcium imbalance may reflect the release of calcium ions from internal organelles. In this regard, lead perturbs and alters the release of intracellular calcium stores from organelles like the endoplasmic reticulum (ER) and mitochondria [59, 60]. Mitochondria can accumulate large amounts of calcium, for example, in the presence of inorganic phosphate. The rise in calcium results in an upregulation of energy metabolism and an increase in mitochondrial membrane potential. Then, the release of this accumulated calcium through a special channel, permeability transition pore (PTP), can cause mitochondrial depolarization. According to the model of glutamate toxicity, mitochondrial calcium accumulation and resultant membrane depolarization are clearly linked to the initiation of a cell death pathway in mitochondria [61, 62].

Microwaves can also affect chromatin conformation and histone phosphorylation in human lymphocytes. Interestingly, in addition to causing genetic damage via oxidative and non-oxidative mechanisms (DNA adducts), certain carcinogenic heavy metals can cause significant epigenetic changes in cells such as DNA methylation and histone modifications. These can result in gene silencing or reactivation of gene expression [63]. MicroRNAs (miRNAs) are highly conserved, noncoding small RNAs regulating the expression of broad gene networks at the posttranscriptional level and may represent another epigenetic control mechanism. In many cases, the specific effects of such epigenetic changes still appear to be unknown and could conceivably impact major cellular functions like cell death and/or proliferation [64].

Apoptosis is involved in maintaining cell number in tissues, and, although increased cell proliferation is necessary, it is not sufficient for cell transformation to take place. Normally, in multicellular organisms, a dynamic balance exists between cell birth and cell death to retain constant cell numbers throughout adult life. This homeostasis depends on an integrated balance between apoptosis (cell death) and mitosis (cell division) such that these two activities are counterbalanced and equivalent. In fact, this homeostatic balance may contribute a critical defense mechanism of the cell to various genotoxic agents such as carcinogens [65].

A permanent loss in homeostatic equilibrium between cell division and cell death may be a critical determinant in the transition to tumorigenesis. The increased proliferation in preneoplastic lesions is often accompanied by a parallel increase in cell death, at least in the initial stages of transformation to cancer. Quantitative histological studies in the rat liver model

have revealed that the rate of apoptosis tends to increase from normal to preneoplastic to malignant cells [66]. Comparative studies with the rat bladder have also suggested that apoptosis is closely linked to chemically induced carcinogenesis [67]. Additional support for this transition comes from a variety of other models [7]. However, ultimately, tumor formation only seems to occur once the cancer cells have become resistant to apoptosis while continuing to proliferate. In fact, acquired resistance to apoptosis appears to be a pivotal event in cell immortalization and the transition to malignancy [65].

In summary, various laboratory studies on animals and certain human data [68] are suggestive that tumor formation requires at least two discrete events to take place in response to a carcinogen. The first involves an elevation of apoptosis in a particular tissue due to a genetic predisposition, stress, or mutation. The second confers resistance to apoptosis in that same tissue resulting in the formation of an abnormal growth due to a dysregulation of cell number homeostasis. Moreover, there is some evidence to suggest that both these events can be reversible when treated with a selective apoptotic agent and, hence, they may be either genetic or epigenetic in nature.

Thus, according to this new model, apoptosis becomes an important focus of study and key determinant of carcinogenic potential for any particular chemical or other complete carcinogen being studied, especially in normal, non-transformed cells derived from the target tissue [11].

In the microwave radiation exposure model, there are a number of cellular processes and responses that appear to lead to the endpoint of an increased rate of apoptosis in both animals and humans. These parameters include DNA damage, alterations in gene expression, metabolic perturbations in intracellular calcium levels, effects on the immune system involving decreases in natural killer cells and T lymphocytes, and bursts in ROS activity. All these biochemical effects represent early events that can trigger or are linked to apoptosis and, therefore, could be involved in initiating an apoptotic model of carcinogenesis as described above.

6. Discussion

Briefly, epidemiological data on the human effects of microwave radiation suggest a predominance of brain tumors and leukemia. In vivo and in vitro animal studies point to genotoxic effects that can trigger apoptosis and detrimental effects on the immune system. Human cell studies corroborate the genotoxic effects of microwave radiation and its ability to cause various kinds of DNA damage resulting in cell death. Possible immune effects are also recorded. These results are in keeping with a two-stage apoptotic model of carcinogenesis [11].

The induction of apoptosis by microwaves in human and rat neural cells and in human lymphocytes correlates well with the increased incidence of brain tumors and leukemia epidemiologically associated with the high-frequency radio waves emitted by cellphone towers. However, further studies need to be conducted on the apoptotic potential of microwaves in non-transformed neural and human lymphocytes at 1800–1900 MHz in order to test this

parameter definitively since significant biochemical differences can exist between transformed and non-transformed cells. Blood cells of children should also specifically be tested since they are susceptible to leukemia from high power voltage (HPV) lines, which emit low-frequency radio waves. The developing tissues of children have already been found to be more susceptible to the penetration of cellphone radiation. According to a new approach to cancer risk assessment, if apoptosis is induced in these normal tissues from adults and children, along with the epidemiological data, this would be sufficient criteria to establish cellphone tower EMR as a complete carcinogen providing that microwave exposure is at a high enough specific absorption rate (SAR).

As an example, sufficiently high SAR levels for microwave radiation are likely to be achieved only very close to or directly in front of cellular antennas mounted on a roof, whereas a distance of up to 400 meters from cellphone towers, which emit more EMR, has been found to be associated with an increased cancer incidence. In any case, access to such rooftop areas with cellular antennas should be restricted or limited [69]. Actually, defraying the total EMR load in this way may be one potential method of decreasing total human exposure in urban neighborhoods. Dividing up the EMR load between several buildings in an urban area could help to minimize overall individual microwave exposure, while having one large cellphone tower in the same area would tend to maximize the microwave exposure of a few.

According to various animal studies, there appears to be a significant effect of microwaves in the cellphone tower frequency range on mammals, avian species, and insect pollinators such as honey bees. There also appears to be a negative impact on plant life in the vicinity of cellphone towers. Decreases in fruit and other crop yields could translate into economic losses. As a result, some countries like India have already taken positive action against the potential threat of cellphone tower EMR to wildlife by proposing to have EMR levels audited and recognized as a pollutant and passing a special law to safeguard the surrounding environment. Other countries should also follow suit in setting safe environmental limits on EMR emission levels from cellphone towers in order to preserve the urban flora and fauna. Such safety standards should always be based on the latest research and must be subject to constant revision as new data become available.

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